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14. ABSTRACT
We report here results from the initial-two years of a longer three-year project carried out at NMSU for the first two years, with the third year at ASU East. This work is directed toward long-range objectives to develop and validate measures of team cognition, and at the same time, perform empirical studies to better understand team cognition in the context of military team environments. This part of the effort focuses on the increasingly common "network centric" military environment in which individuals who are distributed in space communicate, share information, and make critical decisions over a richly interconnected network.

In the first two years of this project we collected data from two experiments to examine the effects of DMEs (Distributed Mission Environments), in which team members are geographically dispersed, on team performance, process, and cognition under high and low levels of workload. In parallel, measures of team cognition were further developed, validated, and extended to DMEs. The setting for this research was a synthetic three-person team task based on USAF Predator Uninhabited Air Vehicle operations. This synthetic task environment is housed in ASU East's (formerly NMSU's) CERTT (Cognitive Engineering Research on Team Tasks) Laboratory. Results indicated minimal deleterious effects of DMEs on performance, but some effects of DMEs on team process and knowledge. In addition there were significant effects of changes in workload on team performance. Not only do results from this proposed work have implications for military DMEs, but they also extend the scientific base of knowledge pertaining to team performance, process, and cognition in DMEs and the specific influence of DME factors such as communication mode, familiarity, and co-presence on team cognition.

15. SUBJECT TERMS
team cognition, distributed mission environments, team performance

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PROJECT OVERVIEW

The progress reported here is part of a long-range effort dedicated to developing and validating measures of team cognition, and at the same time, performing empirical studies to better understand team cognition in the context of military team environments. This part of the effort focuses on the increasingly common military environment in which individuals who are distributed in space communicate, share information, and make critical decisions over a richly interconnected network. Warfare in this environment has been termed "network centric."

The original objectives of this project involved conducting three empirical studies to examine the effects of DMEs (Distributed Mission Environments), in which team members are geographically dispersed, on team performance, process, and cognition. In parallel, measures of team cognition were further developed, validated, and extended to DMEs. This setting for this research is a synthetic three-person team task based on USAF Predator Uninhabited Air Vehicle operations. This synthetic task environment is housed in ASU East's (formerly NMSU's) CERTT (Cognitive Engineering Research on Team Tasks) Laboratory. Not only will results from this proposed work have implications for military DMEs, but they will also extend the scientific base of knowledge pertaining to team performance, process, and cognition in DMEs and the specific influence of DME factors such as communication mode, familiarity, and co-presence on team cognition.

This report summarizes progress during the initial part of this project carried out at NMSU. In December 2002 the PI moved to ASU East and the grant at NMSU was terminated at the end of its second year (and a no cost extension through May 31, 2003 was granted at NMSU). The report that follows the final year at ASU will provide a comprehensive account of the entire three-year project at NMSU and then at ASU. Activities during this initial performance period centered on data collection and analysis associated with two DME experiments (data collection for the second experiment began in 9/1/02 and ended in 12/31/03 and so results are reported here only from the first experiment). Key findings from the first experiment include 1) limited deleterious effects of the distributed manipulation on team performance, 2) significant effects of workload on team performance, 3) suggestions that team composition (i.e., gender mix) and individual differences in working memory account for significant team performance variance, 4) suggestions that these team and individual differences, as well as the timing of knowledge measures (immediately after training or the very end of the experiment) may contribute to recent lack of correlation between knowledge measures and team performance, and 5) favorable results in regard to the measures of knowledge taken at the team level (i.e., holistic measures).

OBJECTIVES

The specific objectives of this project involved conducting three empirical studies to examine the effects of DMEs (Distributed Mission Environments), in which team members are geographically dispersed, on team performance, process, and cognition. In parallel, measures of team cognition were further developed, validated, and extended to DMEs.

STATUS OF EFFORT

We were on track toward accomplishing our objectives in that we have completed the first experiment and summarize the results below. Measures of team cognition were also been advanced and include the development of new holistic measures of teamwork knowledge and situation awareness (i.e., elicited the team level) and the integration some measures of individual working memory capacity into our overall measurement paradigm. We completed the design of the second experiment and data collection associated with it in late 2002.

ACCOMPLISHMENTS AND NEW FINDINGS

Experiment 1: The Effect of Co-Located vs. Distributed Mission Environments on Team Cognition and Performance

Method. Twenty 3-person teams (65% males, 35% females) of New Mexico State University students voluntarily participated in two six-hour sessions in exchange for $6.00 per hour payment to their organization. Participants were randomly assigned to a team and specific role (AVO, PLO, or DEMPC) of the CERTT Uninhabited Air Vehicle synthetic task. Teams were randomly assigned to either a co-located or distributed condition. In the co-located condition team members communicated during missions over headsets, but could see each other and other computer displays. Co-located teams could discuss the task face-to-face between missions and were free to examine other computer displays (e.g., to see what information other team members have access to). In the distributed condition, the DEMPC was located in a separate room and the AVO and PLO were separated by partitions and could never have face-to-face contact or see the displays of other team members. All communication for distributed teams occurred over headsets.

A working memory measure was administered prior to training. Then teams participated in the 1.5-hour training session (individual tutorials and tests followed by skills checks) and seven 40-minute missions over the course of the two sessions. The first four missions were low workload missions with nine targets and the last three were high workload with 20 targets and more mission constraints (hazards, weather, etc.). During missions experimenters observed team process behaviors using an event-based measure and ratings of process behaviors and presented situation awareness queries to participants individually and as a team. Knowledge measures (taskwork, holistic taskwork, teamwork, holistic teamwork,) were administered immediately after training and after the seventh mission. Other measures were also taken during the sessions (e.g. leadership, social desirability, SART, NASA TLX), but are not the focus of this report.

Results and Discussion. Data analyses on the primary measures were carried out during the summer of 2002. Analysis on secondary measures is in progress. This section highlights the main findings relevant to the analysis of the primary measures. Although there was a tendency for co-located teams to have an advantage over distributed teams in low workload missions, whereas distributed teams had an advantage in high workload missions, the co-located vs. distributed manipulation did not significantly affect team or individual performance (see Figure 1). However, performance was affected by workload (Mean team performance scores = 667 for low and 207 for high; $F(1,18) = 608.78, p < .01$), with poorer performance in high workload regardless of condition and with DEMPCs, and to a lesser extent, PLO's, being the roles most affected by an increase in workload. For a number of reasons we believe that the distributed condition does have a deleterious effect on team and individual performance compared to the co-located condition, although the relatively subtle effects of this manipulation may have been masked by low statistical power combined with high variance due to individual and differences that are described in what follows. This hypothesis has motivated the next experiment in which we will better control for individual and team variation.

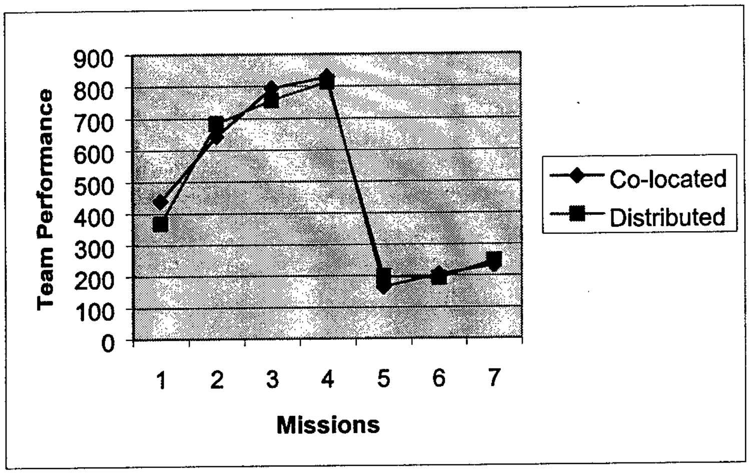

Figure 1. Team performance on UAV task across missions for 10 co-located and 10 distributed teams.

There are a number of reasons that lead us to believe that there is a distributed disadvantage. First, various trends in the performance data are suggestive of this effect. For instance, on the most critical component of the performance score, number of missed photos, co-located teams consistently, though not significantly, miss fewer photos than distributed teams (See Figure 2). Furthermore, team process behavior, measured by proportion of appropriate behaviors at critical mission junctures is significantly better for co-located teams ($M = .63$) than for distributed teams ($M = .48$; $F(1, 18) = 17.30, p < .01$). Also, holistic teamwork knowledge

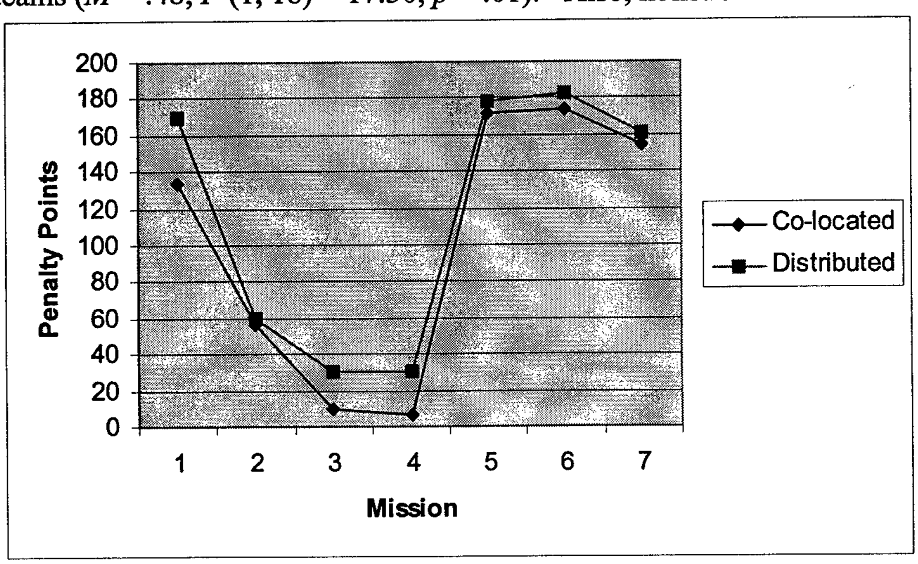

Figure 2. Missed photo penalty points for co-located and distributed teams.

measured at Session 1 was more accurate for co-located teams ($M = 27.6$) than distributed teams $M = 25.8$; $F(1, 18) = 3.9, p = .06$) and several knowledge measures predicted performance differences for co-located teams, but not distributed teams (e.g., teamwork knowledge accuracy). Note that while there were other measures not affected by the location manipulation, there were no measures that favored the distributed condition. Although there were no performance differences in this study due to team member location, the fact that team process and knowledge were affected by location and have been positively correlated with team performance in previous studies, lends support to the proposed distributed disadvantage.

As mentioned previously, our relatively low power, coupled with variance due to individual and team composition differences, may have masked other interesting effects in this setting. To illustrate we have rank ordered the teams in terms of team performance averaged across the seven missions (See Table 1). Note that co-located teams either perform very well or very poorly, while distributed teams tend to cluster in the center of the distribution.

Questions about the low-scoring co-located teams led us to explore some of the individual and team differences data more fully. It turns out that some variance in team performance is due to gender composition of teams with mixed-gender teams performing more poorly ($M = 444$) than same gender teams ($M = 529$). A Chi Square test of mixed vs. same gender by high vs. low scoring teams indicated that this difference is statistically significant ($X^2(1) = 3.81, p = .05$).

In addition, working memory capacity seems to account for additional team performance variance. The working memory task that was used in our study consisted of 32 items. Each item presented the participant with four to seven words and required them to remember the last three words in order. The working memory task yielded a separate score for each member of the team and was administered on an individual basis before the team task began. The importance of the working memory task was recently highlighted by the fairly large correlation ($r(17) = .45, p = .06$) that was found between a component of the DEMPC's working memory score and team performance in high workload missions.

If teams are categorized on the basis of working memory scores and gender composition, we see that Teams 3, 13, and 14 are the only co-located teams that have both mixed gender composition and a low working memory team score (i.e., below a median cutoff; see Table 1). Performance across all seven missions is plotted in Figure 3 for the distributed teams and these two groups of co-located teams. In other words, these co-located teams lacked both the gender composition and working memory capacity associated with high performing co-located teams. When these three teams are removed from the analysis, the co-located team performance mean across all missions is 519 compared to 467 for the distributed teams. Whereas this overall difference is only marginally significant ($t(15) = 1.65, p = .12$), the low workload team performance difference of 741 for remaining co-located teams and 657 for distributed teams is significant ($t(15) = 2.36, p = .03$). The difference for high workload missions (co-located $M = 221$, distributed $M = 213$) is not significant.

Table 1. Teams ranked in order (lowest to highest) of team performance score. (Team 20 was excluded due to missing data.)

Team ID	Team Performance	C= Co-located; D=Distributed	Gender Composition	Team Working Memory Score (bold, italics = below median)
5	338	DIS	**Mixed**	59
14	351	**COL**	**Mixed**	***50***
3	369	**COL**	**Mixed**	***50***
17	376	DIS	**Mixed**	***42***
13	378	**COL**	**Mixed**	***51***
8	422	**COL**	**Mixed**	61
6	457	DIS	**Mixed**	57
12	473	**COL**	**Mixed**	57
21	478	DIS	**Mixed**	***55***
7	480	**COL**	Same	***41***
15	482	DIS	**Mixed**	59
4	492	DIS	**Mixed**	***48***
19	504	DIS	**Mixed**	67
9	513	DIS	**Mixed**	***53***
1	550	**COL**	Same	63
2	552	**COL**	Same	62
16	565	**COL**	Same	***23***
10	568	DIS	Same	60
11	586	**COL**	**Mixed**	69

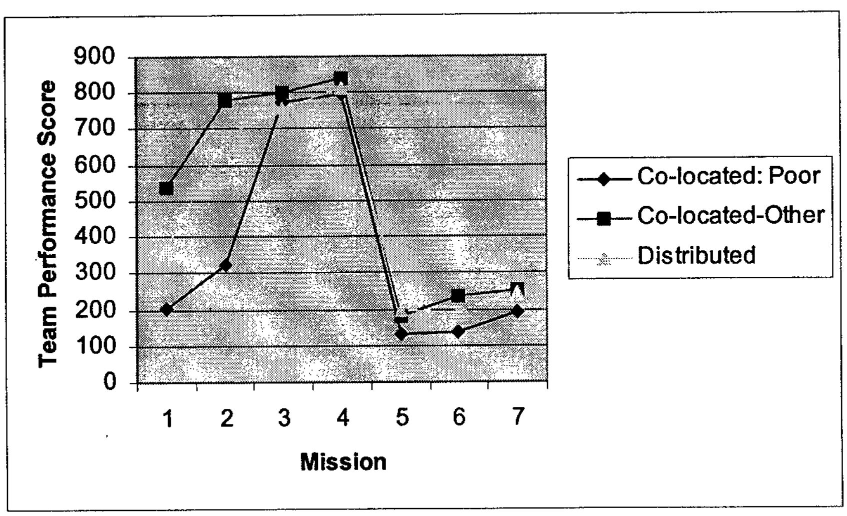

Figure 3. Team performance for distributed teams, three co-located teams (mixed and low working memory), and remaining co-located teams.

So individual and team differences not only seem to play a major role in this task, but it appears that by controlling for or statistically co-varying such differences, some of the more subtle effects due to environmental or training manipulations previously masked by such variation may be highlighted. These differences may have been more pronounced in this study and the previous one, due to the fact that the Air Force ROTC participant pool used in the first study had been depleted and so teams were composed of members from different organizations including Army ROTC, rugby club, criminal justice organization, psychology club, etc. We plan to explore these individual and team differences in the proposed effort as well as in the study planned for the fall of 2002. In this study, an additional cognitive individual difference measure will be piloted and teams will be more homogeneously composed.

The pattern of results associated with the knowledge measures is also worthy of mention. Similar to our previous study on knowledge sharing, the degree to which knowledge measures were predictive of performance was weak at best. In some cases (e.g., taskwork role knowledge of Session 2) the correlations with performance were negative (r (18) = -.67, p<.10). Further, in this study, the manipulation of location had little effect on knowledge. Note that situation awareness measures taken at each mission and the holistic measures of knowledge fared better than individual teamwork and taskwork knowledge measures on these grounds. In our first CERTT Lab study, however, knowledge was more predictive of performance than in recent studies. One possible difference between Study 1 and recent studies that could help to explain this lack of correlation is the timing of the knowledge sessions. In Study 1 knowledge was first measured after Mission 1, whereas in recent studies it was measured after training and before Mission 1. Further in both recent studies later knowledge measures were taken *after* the last mission as opposed to *before* the last mission in Study 1. Thus, timing of the knowledge session (either too early for learning or too late for motivated responses) may have contributed to the poor performance of the knowledge measures in the last two studies. In addition, the individual and team variance described previously may also contribute to this outcome. In particular, the negative correlation between taskwork role knowledge and performance seems to be exacerbated by the low scoring co-located teams.

Another noteworthy pattern related to the knowledge measures is based on testing for the additive effects of team process and holistic knowledge on team performance imputed by the framework for team cognition (see Figure 4). First, hierarchical multiple linear regressions were run controlling first for collective team knowledge, and then for team process. Each model was based on three measures of team knowledge at both the collective (measured individually and then aggregated) and holistic (elicited at the team level) levels: taskwork knowledge, teamwork knowledge, and situation awareness. Models were obtained separately for the first set of taskwork and teamwork measures and the second set, with the first set obtained after training and the second set obtained after all seven missions (4 low workload and 3 high workload) had been completed. The critical incident process and situation awareness measures were averaged over the 20 teams separately for high or low workload, and co-located or distributed. Asymptotic performance in low workload (Mission 4) was used as the performance score for the low workload models. For high workload, performance scores from missions 5-7 were averaged. Each of these measurements was taken for ten teams in each condition. Finally, each condition was modeled for both knowledge sessions. These results appear in Table 2.

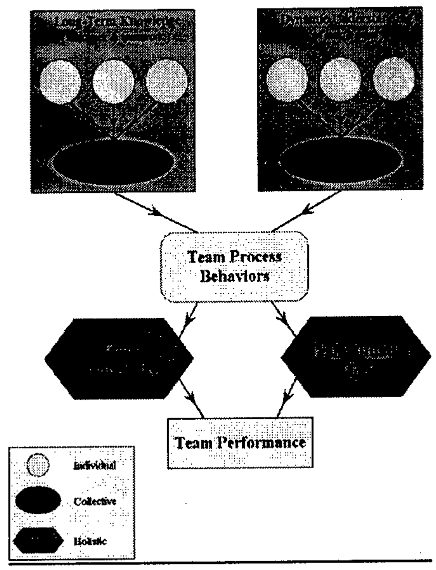

Figure 4. Framework for understanding team cognition.

While these results are admittedly based on rough estimates and small samples, some interesting patterns emerge. Knowledge measurements taken prior to any missions show a different pattern of performance variance accounted for across conditions than do knowledge measures taken after all missions. First, this finding lends support to the conclusion that session timing is critical. More specifically, performance variance attributable to collective knowledge increases for co-located teams between the two knowledge sessions. Distributed teams show no such change, while accounting for just as much overall performance variance via the later influence of holistic knowledge which accounts for performance variance orthogonal to the variance accounted for by collective knowledge measures and critical incident process alone.

The differential impact of collective knowledge on team performance for co-located and distributed teams after all missions have been completed may be suggestive of the differential formation of team knowledge structure, depending on whether the team is co-located or distributed. The collective measures were aggregated using the arithmetic mean of team member's knowledge accuracy scores, while the holistic scores are some function of individual team member knowledge and the exchange of that knowledge with other team members. It has been suggested that the arithmetic mean is an appropriate team-level aggregation method when the individual scores can also be combined additively (Barrick, Stewart, Nuebert, & Mount, 1998). Thus, output in an additive task environment might best be described via a team process in which members have relatively homogeneous input knowledge, while the inadequacy of such a process in describing team output may suggest other, more heterogeneous knowledge structures; e.g., those found in compensatory, conjunctive, or disjunctive task environments (Steiner, 1972), whose processes may best be described via input variance, input minimum, and input maximum, respectively. The results found here using knowledge measured after all missions might imply that co-located teams operated in a more additive task environment than did distributed teams, and presumably, by the end of all their missions, had a more homogeneous team knowledge structure than did distributed teams.

Table 2. Change in proportion of variance accounted for in team performance from hierarchical multiple linear regression models from the framework for team cognition.

Knowledge Session 1		
Step	Co-located-Low	Distributed-Low
Collective Knowledge	$\Delta R^2 = .159$ (-)	$\Delta R^2 = .346$ (+)
Critical Incident Process	$\Delta R^2 = .027$ (-)	$\Delta R^2 = .251$ (+)
Holistic Knowledge	$\Delta R^2 = .706$ (+)	$\Delta R^2 = .209$ (-)
	Total $R^2 = .892$	Total $R^2 = .806$
	Adj. $R^2 = .515$	Adj. $R^2 = .127$
	Co-located-High	Distributed-High
Collective Knowledge	$\Delta R^2 = .176$ (-)	$\Delta R^2 = .146$ (-)
Critical Incident Process	$\Delta R^2 = .073$ (-)	$\Delta R^2 = .091$ (-)
Holistic Knowledge	$\Delta R^2 = .640$ (+)	$\Delta R^2 = .602$ (+)
	Total $R^2 = .888$	Total $R^2 = .839$
	Adj. $R^2 = .498$	Adj. $R^2 = .276$

Knowledge Session 2		
Step	Co-located-Low	Distributed-Low
Collective Knowledge	$\Delta R^2 = .549$ (+)	$\Delta R^2 = .318$ (-)
Critical Incident Process	$\Delta R^2 = .000$ (-)	$\Delta R^2 = .087$ (-)
Holistic Knowledge	$\Delta R^2 = .152$ (-)	$\Delta R^2 = .487$ (+)
	Total $R^2 = .701$	Total $R^2 = .892$
	Adj. $R^2 = -1.39$	Adj. $R^2 = .135$
	Co-located-High	Distributed-High
Collective Knowledge	$\Delta R^2 = .772$ (+)**	$\Delta R^2 = .293$ (-)
Critical Incident Process	$\Delta R^2 = .158$ (+)**	$\Delta R^2 = .000$ (-)
Holistic Knowledge	$\Delta R^2 = .056$ (+)	$\Delta R^2 = .633$ (+)
	Total $R^2 = .986$	Total $R^2 = .926$
	Adj. $R^2 = .890$	Adj. $R^2 = .409$

*$p<.10$ **$p<.05$; $N = 10$; + or - indicates the measures influence on adjusted R^2

Note: for both collective and holistic, knowledge is comprised of taskwork knowledge, teamwork knowledge, and situation awareness.

Experiment 2: The Effect of Co-Located vs. Distributed Mission Environments on Team Cognition and Performance Controlling for Team Composition

In this study we repeat the procedures of Experiment 1, experimentally controlling for gender composition of teams (no mixed gender teams) and statistically controlling for working memory differences. In addition, only five missions, the fifth a high workload mission, will be completed and team knowledge will be measured only once – after Mission 3 (see Table 3). By removing some of the sources of variance in the previous study we hope to get a clearer picture of any effects of distributed vs. co-located mission environments on team cognition and performance.

Table 3. Protocol for fall 2002 experiment.

Setup	30 min
Consent	15 min
Working Memory & Processing Speed Measures	40 min
Training Tutorial	45 min
Skills Training30 min	
Break	10 min
Mission 1	40 min
Mission 2	40 min
Break	10 min
Mission 3	40 min
Knowledge Session	30 min
Break	10 min
Mission 4	40 min
Mission 5	40 min
Debrief	10 min
Backup data	5 min

OTHER PROGRESS IN THIS PERIOD

- Completion of upgraded experimenter workstation (better data recording capabilities and better participant monitoring capabilities, particularly in the distributed condition) and a remote participant workstation.
- Initiation of plans for a not-for-profit, independent research institute that extends work with AFOSR in CERTT Lab to include other studies of distributed sociotechnical systems. This will be located in Mesa. AZ. Dr. Cooke has accepted a tenured full professor position at Arizona State University, East to begin in January 2003.

- US Positioning (CERTT Lab developer) demonstrated Internet2 connectivity between the CERTT Lab's UAV tasks and Brooks AFB C3STARS lab in a recent distributed simulation.
- The CERTT Lab and research focusing on UAV command-and-control will be the topic of a lead article in an upcoming *Unmanned Vehicles*.

IMPLICATIONS

- CERTT facility improvements will facilitate experimenter monitoring, data collection and analysis and move toward collaborative and distributed simulations. These improvements have made the experiments associated with this effort possible and will enable us to more directly address Air Force critical questions about distributed mission environments and training.
- Distributed mission environments, while affecting team process behavior, and team knowledge in negative ways and potentially stifling cognitive homogeneity of team members, have little affect on team performance. This preliminary result has positive implications for the effectiveness of distributed environments in military and civilian applications (e.g., distance education). However, this result should be interpreted with caution until additional data have been collected.
- On the other hand, recent research has demonstrated the significant impact of individual differences in working memory and team composition differences (i.e., gender) on team performance. We plan to direct our work toward the investigation of these factors, particularly those relevant to individual and team cognition. The ability to account for significant variance in team performance has implications for training, selection, team composition, and design interventions that can improve that performance.
- The UAV ground control task involves significant team cognition in terms of background knowledge, information sharing, and team situation awareness. Our holistic measures taken at the team level seem to do a good job at representing team knowledge and thus have potential for performance prediction. Performance prediction is necessary for assessment and eventual diagnosis of team performance. Measures of team knowledge extend outcome data and help move from assessment of performance toward its diagnosis.

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PUBLICATIONS

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INTERACTIONS/TRANSITIONS

Presentations Resulting from Previous AFOSR-Supported Efforts
*presented since October 1, 2001

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*Cooke, N. J., & Shope, S. M. (2001). The CERTT-UAV Synthetic Task: Validity, Flexibility, Availability. Paper presented at the Air Force Office of Scientific Research Workshop on Team Performance, October 16-17, Fairfax, VA.

*Cooke, N. J. (2001). Team Cognition: What Have We Learned? Paper presented at the Air Force Office of Scientific Research Workshop on Team Performance, October 16-17, Fairfax, VA.

*Cooke, N. J., & Shope, S. M. (2002). The CERTT-UAV Task: A Synthetic Task Environment to Facilitate Team Research. Paper presented at the Advanced Simulations Technologies Conference, April 14-18, San Diego, CA.

Consultative and Advisory Functions

AFRL, Brooks AFB
In November of 2002 we (CERTT Lab and US Positioning) participated in an Internet2 demonstration with AFRL at Brooks AFB (Sam Schifflet, Phil Tessier) and Veridian (Charlie Dean). The CERTT Lab's UAV task was connected over the internet with the C3STARS AWACS task at Brooks. The demonstration was successful.

AFRL, Mesa, AZ
In January 2002 Nancy Cooke and Steven Shope presented their vision of an independent research institute which would serve as a research hub for government (AFRL in Mesa), university (NMSU, ASU), and industry (US Positioning affiliates). Dee Andrews of AFRL was present for this meeting.

Army Research Lab
The NMSU Department of Psychology has been involved in a large ARL-sponsored consortium for advanced decision making technologies. The CERTT Lab has participated in this effort in several ways: 1) identifying tasks or scenarios that can be studies in a distributed way across the consortium and 2) sharing event log data for a project focused on analyzing sequential behavior. In October of 2001 the CERTT Lab was demonstrated to Mike Strub, Linda Pierce, Laurel Allender, and Larry Shattuck during a site visit. Other contacts regarding Army UAV concerns have also been made through Mike Barnes at Fort Huachuca, Jay Shively at NASA Ames, and Lila Laux at MicroAnalysis and Design.

Office of Naval Research
Nancy Cooke is also involved in an ONR-supported effort (Susan Chipman) with Peter Foltz. This effort focuses on automating the analysis of team communication data. The three year grant ends in March 2003.

Army Research Institute
Nancy Cooke is serving in an advisory capacity to Adrienne Lee, PI for an Army Research Institute grant to explore the transfer of distributed or co-located training to distributed or co-located mission environments. The first experiment for this grant is being conducted this year (summer and fall 2002).

UCSD
Nancy Cooke serves as a consultant to various VA grants of Matt Weinger, a UCSD anesthesiologist. This work concerns anesthesiology expertise and teams in the operating room.

DIA/NTSB
Nancy Cooke, Janie DeJoode, and Steve Shope have recently (August 28) observed a mass disaster simulation at Denver International Airport at the request of the NTSB (Jim Strusacker). Command and control centers were observed and observations and recommendations are forthcoming.

Transitions

None to date, but we anticipate a number of opportunities for immediate technology transition through the new research institute and its close affiliation with US Positioning.

INVENTIONS

None

HONORS/AWARDS

Nancy Cooke elected Fellow of the Human Factors and Ergonomics Society (2000)

PERSONNEL SUPPORTED

Faculty:
Nancy J. Cooke

Post Doctoral Associate:
Brian Bell

Graduate Students:
Janie DeJoode
Rebecca Keith

Subcontractor/CERTT Developer:
US Positioning: Steven M. Shope

ASSOCIATED PERSONNEL

Faculty:
Peter Foltz
Doug Gillan
Adrienne Lee
Kenneth Paap

Graduate Students:
Greg Bromgard
Jamie Gorman
Preston Kiekel
Harry Pedersen